SEAFRAME

2008 • VOLUME 4 • ISSUE 1 Carderock Division Publication

Innovation Leads to Superior Warfighting Capability

Unique Design for Oceanic Naval Transport Vessel

Implosion Research Increases Sub Safety

Diesel Fuel Discharge Reduced

NAVAL SURFACE WARFARE CENTER

Report Documentation Page

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FROM THE TOP

INNOVATION LEADS TO SUPERIOR WARFIGHTING CAPABILITY

By Captain Mark Thomas, C. Randy Reeves, and Captain Mary Logsdon

For the first time in history, the United States Navy, Marine Corps, and Coast Guard have created a unified maritime strategy called *"A Cooperative Strategy for 21st Century Seapower."* This strategy was developed with the goals of keeping the United States strong, protecting our citizens and homeland, and working with our friends and allies. An important aspect of meeting those goals is providing superior warfighting capability through leading edge, state-of-the-art technology–in a word, innovation.

Carderock Division exists for the warfighter. Therefore, we must look at technology and innovation that provide a unique, advanced capability for the warfighter. To do that, we must promote an environment for innovation, one which fosters innovative thinking and invention. We enjoy a rich heritage in this area and are determined to open the field even wider.

Our senior scientists and engineers are well versed in conceptualizing to advance the state of the art. However, we are also actively engaged in searching out training opportunities and conferences, as well as welcoming guest lecturers as a way to nurture innovative thinking in all of our employees.

A new effort in FY 08 is the creation of a "Command Challenge" by which we will regularly present a topic, related to Navy interest items, for resolution. Our employees will be challenged to develop a creative solution to the problem. Our Science and Technology Council will evaluate the submissions. Feasible ideas will be granted funding for further exploration.

A third initiative in promoting innovation involves bridging the gap between the more experienced workforce and the experts of the future. Our experienced workforce typically communicates its knowledge using formal media, such as reports and forums. We are exploring new ways to facilitate the exchange of information through social networking, blogs, wiki, and instant messaging–forums with which younger engineers and scientists often prefer to work. We're also working to formalize mentoring within the Division.

We are also relying on continuing modes of promoting innovation, such as the Division's Innovation Center. This center has been operating successfully for more than 16 years. It is a special high-tech support system which offers multi-disciplinary teams an environment in which to investigate high-risk, high payoff solutions to Navy engineering and R&D challenges or problems and perform accelerated exploration of new ideas. One such project is the Unmanned Vehicles Sentry System for Assets at Sea. This study was completed in 2005 by Carderock Division and Space and Naval Warfare Systems Center. Currently, we are building a consortium of government laboratories to further develop the idea of a system of unmanned vehicles to guard at-sea assets, including ships, sea bases, or islands.

This issue of SEAFRAME highlights innovative technologies that are either being installed in the fleet or planned for incorporation on future ships. Featured on our cover, Carderock Division is researching a unique design for the Joint High Speed

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The SEAFRAME staff reserves the right to edit or rewrite all submissions.

On the cover: Our front page features images of the Joint High Speed Sealift (JHSS) model-scale waterjet experiments. The overall goal of this research is to explore designs for a very large trans-oceanic transport capable of speeds at up to 39 knots. Read about JHSS research on page 6. This is one example of Carderock Division's innovative solutions to technological challenges featured in this issue.

Photos provided by Dominic Cusanelli, NSWC Carderock Division.
Cover design by Gloria Patterson, NSWC Carderock Division.

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Sealift, an oceanic naval transport vessel. This article can be found on page 6. Another article, on page 4 details innovative seabasing concepts introduced through the Division's Center for Innovation in Ship Design. State-of-the-art fire suppression and firefighting technologies that are being incorporated into the fleet appear on pages 9 and 17. An article on page 11 explores the Division's efforts in adapting commercial bus piping to move medium-voltage power aboard an all-electric ship. The research behind preventing implosion of submarine pressure hulls and pressure hull systems is detailed on page 13. Other articles in this issue include the development of a computational fluid dynamics model to predict effluent fuel concentration, improvements to the Division's special purpose measurement system used to advance underwater electromagnetic silencing, and the development of a new magnetostrictive material that provides a new avenue to convert electrical energy into mechanical energy. These are but a few of the many technologies Carderock Division is exploring to improve the fleet.

Innovation is a self-perpetuating cycle. An organization, like Carderock Division, which produces state-of-the-art technology, attracts quality people because the work is interesting, stimulating and challenging. This, in turn, helps us stay on the leading edge.

Captain Mark W. Thomas, USN
Charles (Randy) Reeves
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BUSINESS

Strategic Technology Team

Stewarding Our Technical Capabilities

By William Palmer

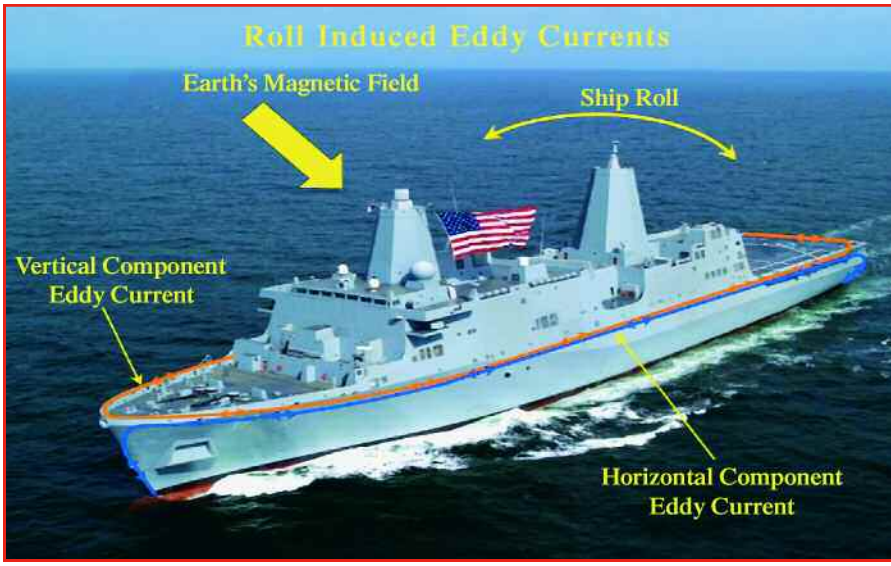
Scientists and engineers at the Naval Surface Warfare Center, Carderock Division, are exploring implementation of new technologies through a Strategic Technology Team. This team was set up within the last five years to address strategic technology-related issues faced by the Division.

At that time, Division leadership saw basic technology issues and strategic thrusts, which needed to be addressed. The effort, which was initiated by former Division Commander Captain Charles D. Behrle (retired USN), established five teams. These teams, which were headed by high-level managers, focused on human capital strategy, business processes, technical processes, facilities, and strategic technology. Project proposals were solicited, resulting in a myriad of areas to be explored. The nature of the proposals had different focuses, with some representing people-oriented projects, such as developing specialized training courses for new employees. Other proposals addressed infrastructure need, stewardship of a particular area of expertise, encouraging work in a certain area of research, or technology development.

The Technology Team, headed by Dr. In-Young Koh and Dr. Joseph Corrado, addresses technical stewardship and technology enhancement issues. This team met several times to develop criteria, ranking schemes, and weighting factors by which to judge proposals. Department Head concurrence was sought for these criteria, so that department-level perspective was represented.

More than 20 projects have been funded through the proposals to the Technology Teams. Three are highlighted here to give examples of the work done:

Above: In this high-frequency (HF) radar transition project, a HF power amplifier, wideband antenna, and ship tracking capability will be developed. Recent interest in existing and future threats to Navy assets makes the proposed HF radar hardware transition and subsequent data acquisition critical.
Image courtesy of NSWC Carderock Division, Hydrodynamics Department.



Above: One example of strategic technology team involvement is this project, which models eddy current signatures. This task will transform the eddy current signature mitigation process and lower a ship's susceptibility to mines due to eddy currents.
Image courtesy of NSWC Carderock Division, Hydrodynamics Department.

- Magnetic Field Lab Physical Modeling of Eddy Current Signatures. This project builds a model to study eddy currents, which will ultimately help mitigate a ship hull's eddy current signature, and thus lower the ship's susceptibility to mines.
- Next Generation Submarine Air Purification. This effort will complete the basic research necessary to advance this technology, permitting deployment cost and scheduling evaluation.
- High Frequency Radar Transition. This effort will develop a high frequency power amplifier, wideband antenna and ship tracking capability. Recent OPNAV and fleet interest in existing and future threats to in-service, next-Navy, and Navy after next makes the proposed HF radar hardware transition and subsequent acquisition of this data critical.

Because of the time needed to stand up the process of evaluation and selection, as well as the organization of the Technology Team, projects for fiscal year 2007 were the first to receive critical assessment by the team. Each department was asked to submit five to seven proposals, in order to keep proposals to a number the teams could efficiently and expediently evaluate and rank. Adjustments were made to projects having a broad scope, such as extending the project to two-year execution times versus one, to make the project viable and not exceed the program's operating budget.

Currently, fiscal year 2008 projects have been selected and money allocated. Proposals were submitted in mid-summer 2007, with the ranking process completed in mid-August. A list of final projects was given to the Division's Board of Directors in early September. A poster session presentation of the projects was held during Engineer's Week, where BoD members and outside interested parties could review projects with principal investigators.

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SHIP INTEGRATION & DESIGN

AMPHIBIOUS FORCE LOGISTIC SUPPORT

Introducing Naval Design Through Innovative Seabasing Concepts

By Christopher A. Dicks, Ministry of Defence, UK, Steven H. Ouimette, and Dr. Colen G. Kennell,

Synopsized By William Palmer

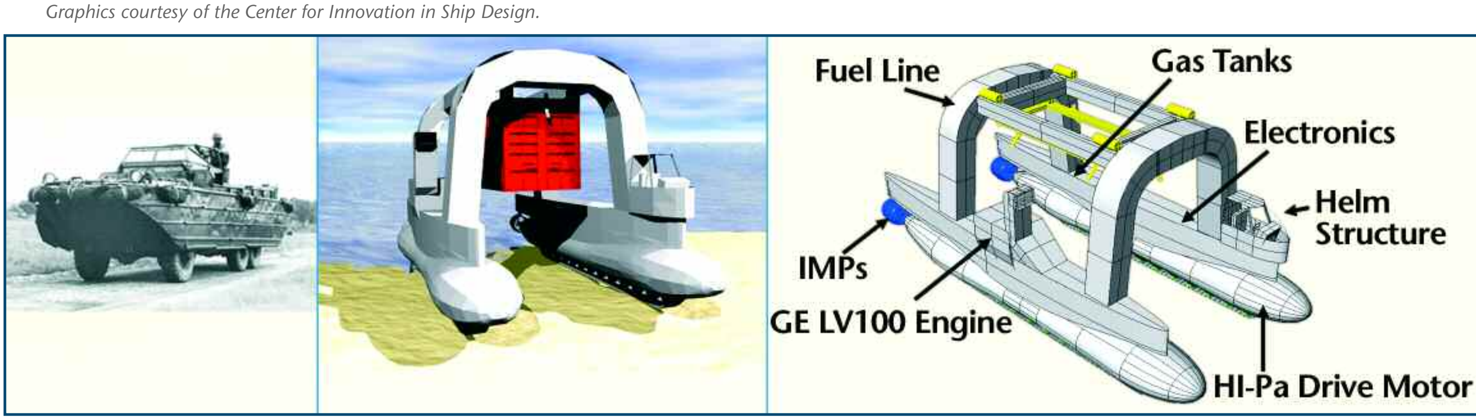
An undergraduate student design intern education program at the Naval Surface Warfare Center, Carderock Division's Center for Innovation in Ship Design (CISD) led to the development of several innovative design concepts to support the U.S. Navy in its requirement to provide logistic support to an amphibious force from a seabase. CISD allows the opportunity for engineering undergraduate interns to undertake 10-week design exercises for ship and system design education and to provide input into U.S. Navy programs in the area of seabasing.

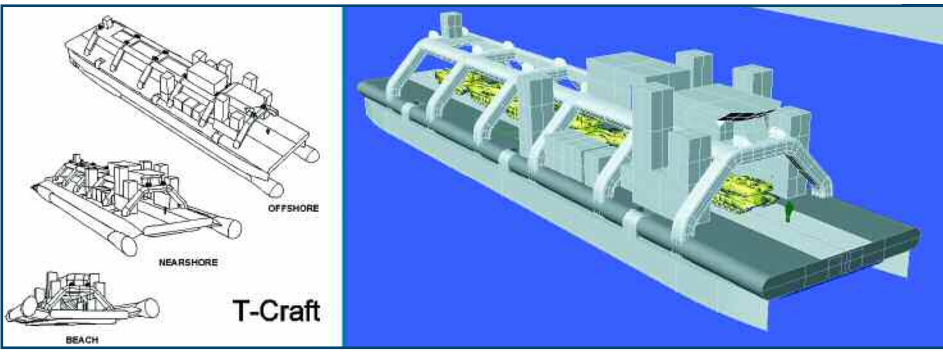
Below: (1) The DUKW-21 is an amphibious tracked vehicle based on a re-imagining of the World War II DUKW concept. It provides cargo transportation from a Sea Base to shore. *Graphics courtesy of the Center for Innovation in Ship Design.*

Seabasing provides a unique operational construct for design education, as many high priority challenges remain unresolved and innovative solutions can be advanced. The solutions to seabasing problems often rely on seemingly simple mechanical or naval design principles operating in harsh and complex environments. Mechanical and naval engineering students gain significant relevant knowledge in a short period of time, despite their limited experience of both engineering and naval matters.

Three design concepts are discussed in this article as examples:

(1) "DUKW-21" is an amphibious SWATH ship/tracked vehicle based on a re-imagining of the World War II DUKW concept. (The letters DUKW are a designation for a specific identity component. "D" stands for 1942, "U" stands for utility, "K" stands for front wheel drive, and "W" indicates two rear-driving axles.)





Left: (2) A transformable craft, or T-Craft, is the focus of this ONR-sponsored project. This vehicle's primary mission is to transfer vehicles at high speed from a sea base through the surf zone to a beachfront. The goal of the proposed design is to carry 10 M1 tanks.
Graphics courtesy of the Center for Innovation in Ship Design.

(2) A Transformable SWATH concept is detailed, potentially meeting the Office of Naval Research (ONR) “T Craft” requirements. The vessel is capable of self-deployment from an intermediate base, loading 7 M1A1 tanks at the sea base, and sailing at high speed to the beach. It then adapts to a hover barge supported mode to provide a true amphibious logistical capability.

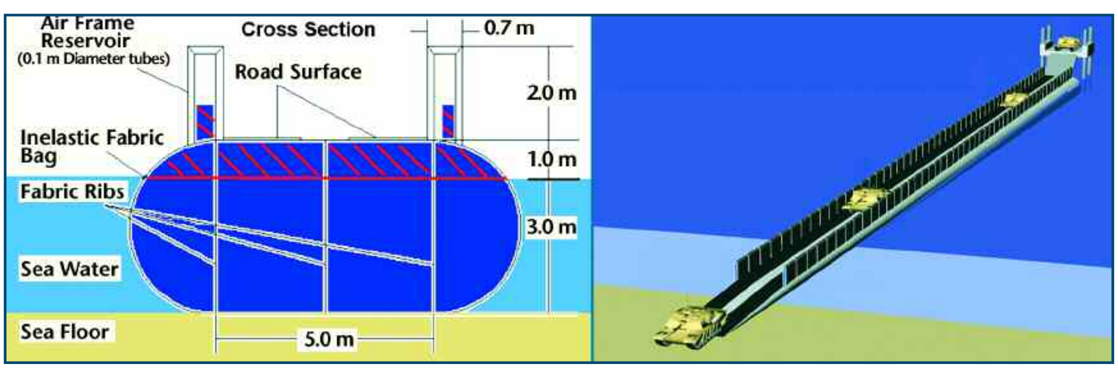
(3) *Moses* details the potential for four-meter deep, water-filled, flexible structures to provide a 150-meter long causeway capable of allowing M1A1 tanks to disembark from vessels directly onto the beach without grounding or using steel causeway systems.

DUKW-21 is designed to transfer a single International Standards Organization (ISO) container from a ship more than nine kilometers offshore to the same distance inland at a speed of 15 knots. An addition to the DUKW-21 concept involved making it autonomous. Current solutions to this logistic issue include either a landing craft/land vehicle combination or helicopters making many trips to transport small loads. These methods are intricate, expensive, slow, and tie up valuable military assets useful for other purposes. Taken to its ultimate conclusion, DUKW-21 could form convoys of autonomous vehicles independently unloading significant quantities of materials on shore. The DUKW-21 design uses two SWATH hulls connected by two arches. The container load is slung below the arches. A single DUKW-21 will be able to load a 20-foot, 24-ton ISO container at the seabase, carry it inland over rough terrain, and unload the container. The containerized-based approach is used as it allows many different cargo types to be carried using a single cargo handling system. A gas turbine generator is used to provide electrical power to a track system and podded propulsors in each hull to provide motive power in all environments. Autonomous control systems are mounted as is a single driver’s operating position.

ONR’s T-Craft program investigates the transfer of vehicles at high speed from a cargo ship at the seabase and carrying them through the surf zone to a point on the beach. T-Craft is intended to significantly increase payload capacity (up to 10 M1 tanks) and provide a “feet dry” beach capability. Running independently from four contractor-led efforts, the “Student T-Craft” innovation team was given the challenge of meeting all the ONR T-Craft requirements but to base it on the concept of a SWATH vessel that mechanically transforms to a hover barge-based land vehicle. The hullform used was one that had previously proven good seakeeping performance and resistance at high speed. Transforming the geometry of the hull to allow amphibious cargo delivery presented a large set of difficult design challenges, as well as learning opportunities.

The primary objective of the *Moses* team was to develop a lightweight, rapidly deployable causeway concept to enable movement of wheeled and tracked military vehicles from shallow draft ships through the surf

Right: (3) This concept is based on lightweight, rapidly-deployable inflatable structures which can be filled with seawater to create a causeway from offshore, through the surf zone, to the beach, without vehicular traffic getting wet.
Graphics courtesy of the Center for Innovation in Ship Design.



AMPHIBIOUS FORCE (Continued on page 6)

AMPHIBIOUS FORCE (Continued from page 5)

zone to shore without wetting the vehicles. The system is not an amphibious assault system, but more a logistics support system for secure beaches without port facilities.

The final design of *Moses* uses the simple concept of an envelope of a flexible, inelastic material pressurized with sea water. The system will extend from the ship to the shore, up to but not limited to, 150 meters away. The bag rests on the sea floor up to a depth of three meters and the top/roadway is elevated one meter above water level. One-meter, water-filled side walls are supported by air beams and provide both the overpressure and protection against green seas. The other main element of *Moses* is the roadway. A rolled carpet of planks will be laid across the surface of the bag. Each individual plank will be attached to the bag to transmit tracked and wheeled vehicle loads into the fabric without damage. The entire system of roadway, bag, and reservoir can unfurl as one operation during deployment and recovery. The total weight of the system is less than 15% of the weight of the current causeway of the same length. A scale model of the *Moses* design was constructed by the students, and experiments verified its capability to remain rigid and of acceptable distortion while scaled loads were applied.

The three concepts detailed all require significant future research and development to prove technical feasibility. However, they each represent an interesting and innovative solution to a very difficult technical challenge, developed by very inexperienced designers in a short period of time. Each team gained a significant amount of knowledge as a result and was able to provide a possible solution that has some merit, as well as significant technical risk, to a real-world challenge.

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Joint High Speed Sealift

Hull Forms & Propulsors

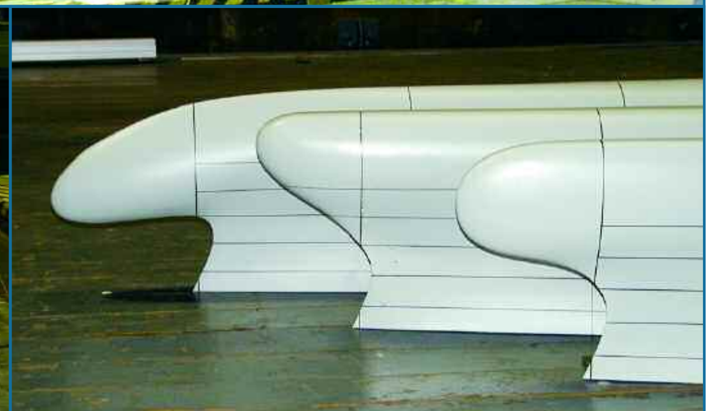
Unique Design for an Oceanic Naval Transport Vessel

By William Palmer

A multimillion-dollar ship research initiative, to support hullform and propeller development for a High Speed Sealift Ship, is being conducted by Carderock Division, Naval Surface

Above: The JHSS model measures about 32 feet in overall length and weighs thousands of pounds. Main purpose of the full-scale ship is to conduct a rapid trans-oceanic crossing of personnel and equipment.
Photo provided by Dominic Cusanelli, NSWC Carderock Division.

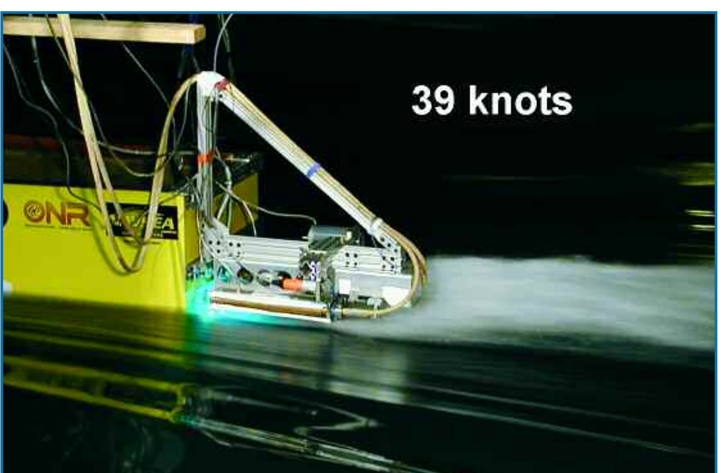
Above: A frontal vew of the gooseneck bulbous bow selected for use on the JHSS model. Bow and stern sections are modular, meaning these sections are interchangeable, avoiding the cost and time of rebuilding models for each design iteration.
Photo provided by Dominic Cusanelli, NSWC Carderock Division.



Above: Three modular bow sections considered during testing. It was found that the gooseneck bulbous bow, far left, yielded the most efficient hydrodynamic performance. As with the aft section, modular bow sections were used to ease transition between bow sections.
Photo provided by Dominic Cusanelli, NSWC Carderock Division.

Warfare Center researchers. Models with various propulsor configurations are being tested. The latest iteration of the model, about 32 feet in length and weighing several thousand pounds, is propelled by four axial-flow waterjets. “We are using the very latest state-of-the-art instrumentation and analysis techniques,” says Gabor Karafiath, one of the project’s principal investigators. “I am not aware of any other organization that has done any waterjet testing with models of this size and this complexity anywhere in the world.”

Below: The JHSS model moving through the David Taylor Model Basin at 39 knots. Laser light helps researchers measure the velocity and direction of fluid flow through the waterjet propulsion system.
Photo provided by Dominic Cusanelli, NSWC Carderock Division.



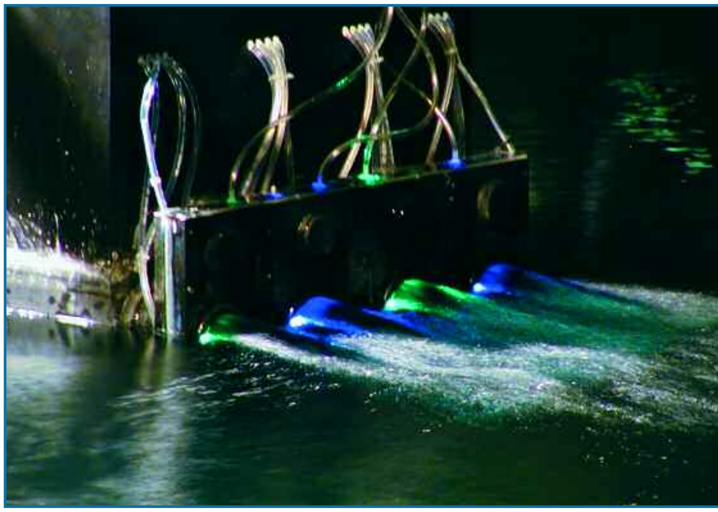
Development of this ship design will allow the Navy to move equipment and personnel across the ocean as quickly as possible. A full-scale vessel, at more than 900 feet in overall length, can move through the water at speeds up to 39 knots.

The design of the hullform, propulsor, and the entire ship utilizes all known information about hydrodynamics and propeller design, and is an all-out effort to make the design’s hydrodynamic aspects such that the 39-knot top speed is achievable. Model testing and analytic work to date indicate that the goal has been accomplished.

The baseline model, which has a scale ratio of 34.121 (multiplying scale ratio times the model length gives full-scale vessel length), was tested for resistance and powering characteristics in both calm water and in waves, first with standard bladed propulsors with struts and shafting. Then, the model was modified to accommodate four waterjets, the nozzles of which were mounted in line across the model’s stern. Water flow through the waterjets was measured by laser Doppler velocimetry, a technique perfected at Carderock Division’s West Bethesda site. Current waterjet technology was used in a Mixed-Flow waterjet variant, but was altered to be much larger in size and power than is commercially

JOINT HIGH SPEED SEALIFT (Continued on page 8)

JOINT HIGH SPEED SEALIFT (Continued from page 7)



Above: Blue and green laser light helps researchers measure internal flow in waterjets. Plastic tubes above nozzles are pressure measurement tubes and measure the pressure on the sidewall of the water jet exit nozzle. From these pressures, an independent measurement of waterjet exit velocity can be deduced.
Photo provided by Dominic Cusanelli, NSWC Carderock Division.

Above: The JHSS model being tested at 42 knots. Propulsion testing consists of four phases, starting with a baseline strut/shaft configuration, then using axial-flow and mixed-flow waterjets, and finally podded propulsors. Modularity of stern section avoids reconstruction of model for each propulsor configuration.
Photo provided by Dominic Cusanelli, NSWC Carderock Division.

available. In addition, a second, more compact waterjet variant, based on newly-emerging axial waterjet technology, was also evaluated.

Direction of the design is being steered by the Hull Working Group (HWG), the engineers and scientists of which are tailoring, driving, and deciding what paths to take for the hullform. As the project is largely in the research and development phase, the group is directing the decision-making process in that arena. Specific design tools have been developed to help researchers in optimizing the model. One of these tools is a computer program that simulates flow through a waterjet, and calculates various flow aspects through the waterjet system.

As many as five years ago, other sealift designs were being considered, and ship design personnel learned much from those designs about hull shaping and design facets conducive to high speed powering. Those lessons were incorporated into the present effort. In addition to the powering applications, three different bulbous bow designs were used, with the "gooseneck" bulb yielding the most hydrodynamic efficiency. A stern flap, an invention pioneered by Dominic Cusanelli, another principal investigator, was added to the hullform to further improve efficiency.

The next step in the process is to look at the third propulsor alternative, which will utilize electric podded propulsors in various configurations. The preferred arrangement for testing of these propulsors is as a set of contra-rotating propellers, with the forward propeller being driven from the front side with conventional shafts, and the aft propeller would be an electrically-driven tractor pod. Research shows that this arrangement yields extremely high propulsive efficiency.

The bulk of testing was done in the Carriage 2 towing basin at West Bethesda, but the model also saw action in the wavemaker section of the Maneuvering and Seakeeping facility. Maneuvering testing has been conducted at the nearby Triadelphia Reservoir.

Testing and design efforts are still underway, and conclusions of these R&D activities, will form a baseline with which the Navy can judge similar designs originating from industry, and the computational tools used to verify this type of design can also be used to verify any industry proposals.

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MACHINERY SYSTEMS

Autonomic Fire Suppression System

Successfully Transitioning from Concept to Acquisition

By Don Dalessandro and Leslie Spaulding

In a ship fire, the fire can spread vertically in three minutes–not much time to begin suppression efforts. Additionally, if the fire results from a weapons effect, the ship's piping systems (such as the firemain and chilled water) and ship structure can be compromised–making suppression even more difficult. During this type of event, the environment is not hospitable for a manual response because the spaces are compromised with jagged metal, smoke, and fire. Tests were conducted onboard the ex-*USS Shadwell*, a decommissioned United States Navy Landing Ship Dock that serves as the Navy's full-scale damage control research, development, test and evaluation platform. These tests showed that even highly trained damage control teams can have their response time significantly slowed by the difficult environment. Moreover, this problem will be further complicated as manning levels are reduced for future ship classes being built by the Navy.

Naval Surface Warfare Center, Carderock Division's (NSWCCD) Machinery Research and Engineering Department is the Navy's primary agent for the research and development of advanced machinery systems and components and the life cycle manager/in-service engineering agent for many machinery systems and components during acquisition and the ship's life.

Research on automating damage control systems to reduce manning has been ongoing since the 1970s. During the 1990s under the sponsorship of the Naval Sea Systems Command, NSWCCD developed the fundamental concepts and components that have become the Autonomic Fire Suppression System (AFSS). The resulting AFSS provides the means for putting fire suppression directly on a ship's primary damage area (point of hit/fire) via an adjacent compartment without crew participation.

AFSS consists of several components. One of the key technologies is a device-level, control-based, multi-mode smart valve for fluid system break detection and isolation developed jointly by NSWCCD, industry, and academia. A smart valve contains an actuator, onboard fluid sensors, microprocessor, and network communications interface, as well as specific application software that supports autonomous control operations. This technology, in effect, automatically isolates a piping rupture by detecting pressure and flow variations, preventing a loss of pressure in the piping system.

The AFSS design also employs a sidewall medium-pressure watermist nozzle that penetrates the sub-division bulkheads into the primary damage area. These nozzles were developed through a teaming effort between Carderock Division, Tyco Grinnell, and Hughes Associates. Medium pressure, 250 to 300 psi, does not require the same level of certification as higher pressure piping systems. Medium-pressure nozzle performance provides adequate suppression for Class A fires and to prevent fire spread. Therefore, by using medium-pressure piping systems, the Navy will save money in construction

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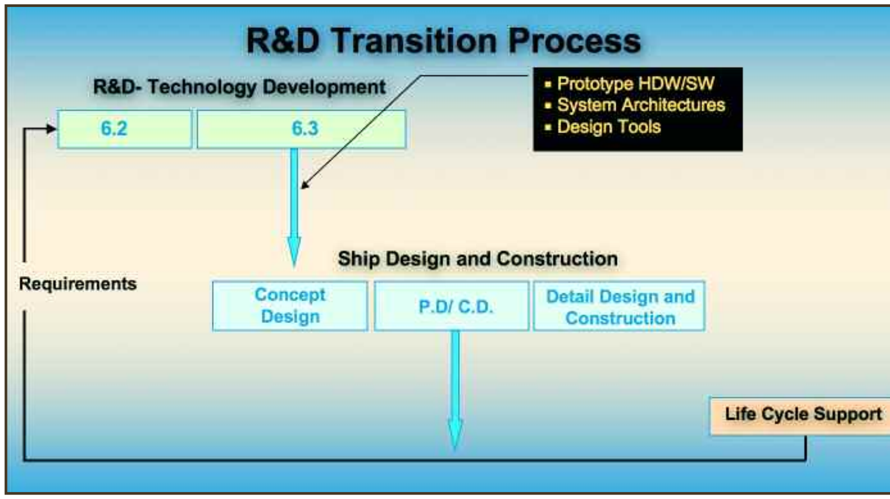
AUTONOMIC FIRE SUPPRESSION (Continued from page 9)

costs but still reap the firefighting benefits of watermist nozzle technology.

Another component of the AFSS is the piping system architecture. The forces caused by a weapons effect can severely deform and even rupture firemain piping. Carderock Division developed and demonstrated the “S” header. This new firemain architectural component helps reduce the impact of weapons-induced damage to the fixed piping system in the primary damage area and adjacent sub-divisions.



Another piping system concept defined and tested by Carderock Division was the flexible hose coupling that would connect the fixed piping system in an adjacent compartment and with a side wall watermist nozzle. The flexible hose coupling was designed to take up the stresses generated for a failed bulkhead that would be translated between the adjacent space piping system and the sidewall nozzle. This design allowed the watermist nozzle to remain effective even when the bulkhead on which the nozzle was mounted had failed from a weapons effect blast.

All of the AFSS technology was developed and initially tested at Carderock Division’s Briar Point Survivability Test Site at the Aberdeen Proving Grounds Test Center in Maryland. As part of their role to foster state-of-the art knowledge of technology for military applications, NSWCCD technical experts briefed both of the competing industry teams conducting design studies for the DD(X) on the AFSS concept. With the award of the DD(X) contract, the participation of NSWCCD technical expertise in developing the AFSS was funded by the lead contractor under a Work for Private Parties agreement. NSWCCD was part of the team that demonstrated the effectiveness of the overall AFSS system on the ex-*USS Peterson* (DD 969) in 2004. AFSS is now fully accepted by the Navy for the DDG 1000 design and is being incorporated by Bath Iron Works into the class’ firemain system. Additionally, the smart valve technology is being incorporated in the ship’s chilled water system to ensure there is no negative impact to the chilled water feed to the Electronic Module Enclosures aboard ship.

The AFSS is a completely autonomous fire fighting system that requires no human involvement, greatly increasing survivability of the ship in a damage scenario, while eliminating the need to place humans in harm’s way. Carderock Division remains involved in the DDG 1000 AFSS system design and acquisition, providing technical consultation on this system, as well as developing software algorithms for use on the ship. In addition, the NSWCCD Machinery Research and Engineering Department is working with the Office of Naval Research and academia to find a more innovative, cost-effective approach to producing the smart valves.

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MACHINERY SYSTEMS

ADAPTING COMMERCIAL DEVELOPMENTS FOR FUTURE NAVY SHIPS

Using Insulated Bus Pipe for Shipboard Transmission Lines

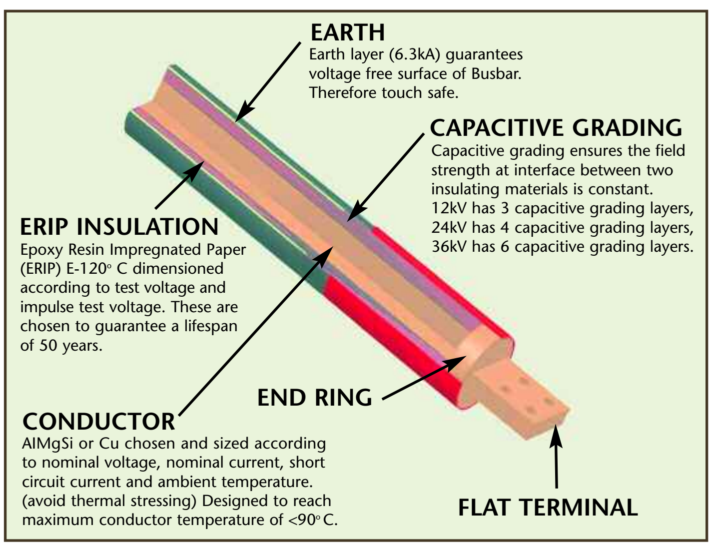
By Rick Worth and Leslie Spaulding

The All-Electric Ship requires medium voltage power to be moved about the ship to meet the increased power requirements of the mission loads needed to enhance Navy future warfighting capabilities. The additional electrical cable to distribute medium voltage uses valuable space and adds weight. Naval Surface Warfare Center, Carderock Division, Philadelphia is investigating whether insulated bus pipe (IBP) can save the Navy time, money, weight, and space compared to conventional medium voltage cable. In addition, IBP holds the potential for new Navy electrical distribution system designs which will reduce vulnerability, enhance survivability, and reduce ship fabrication costs.

Medium voltage applications require paralleling multiple cables to distribute power. Restrictions in bend radii and handling of the large cable can force a ship system designer to parallel smaller, more manageably-sized cables. Paralleling cables increases the time to install medium voltage termination kits on all of the ends of the cables. Also, limited space inside terminal connection point boxes can necessitate an auxiliary connection box because the original terminal box size restriction could prevent adequate working room required to attach and torque the terminal bolts. The higher ampacity of IBP decreases the total volume of conductor required to distribute medium voltage. IBP can have a tighter bend radius. The complexity of the IBP hanger system is significantly reduced compared to traditional medium voltage cable, saving additional space and weight.

IBP has been used in land-based installations, such as industrial facilities and electric power utility substations, for more than 50 years. Passenger cruise ships began using the technology about 12 years ago. The cruise shipbuilders took advantage of the IBP's tight bend radii to deliver power to space constrained areas of the ship requiring high power, including podded propulsors.

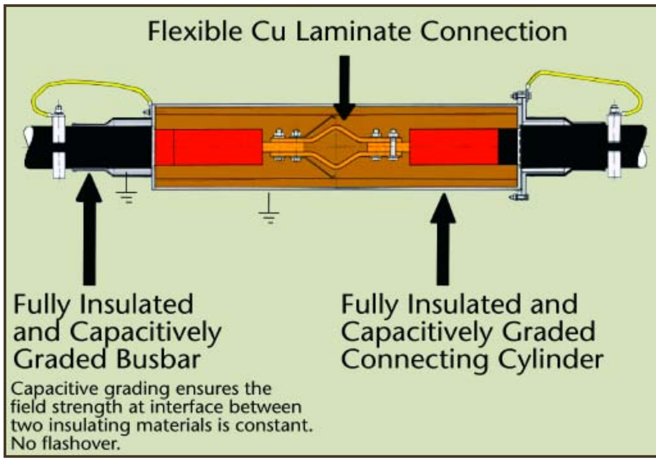
Additionally, IBP can support modular ship construction, something traditional cable cannot. In modular construction, the shipbuilder fabricates the ship in sections that are outfitted with equipment, piping, and electrical pathways. The modules are then brought together, and the piping, HVAC, and electrical systems from each module are connected to the adjacent modules. Traditional cable eliminates many of the advantages of modular construction; it either has to be installed after the sections are brought together, or additional connection points must be added to the distribution system, adding time and increasing cost. Using IBP, the shipbuilder can



Basic IBP construction.
Graphic by MGC Inc.

ADAPTING (Continued on page 12)

ADAPTING (Continued from page 11)



Above: IBP Connecting Cylinder.
Graphic by MGC Inc.

Above: IBP Installation with pipe joints.
Photo by MGC Inc.

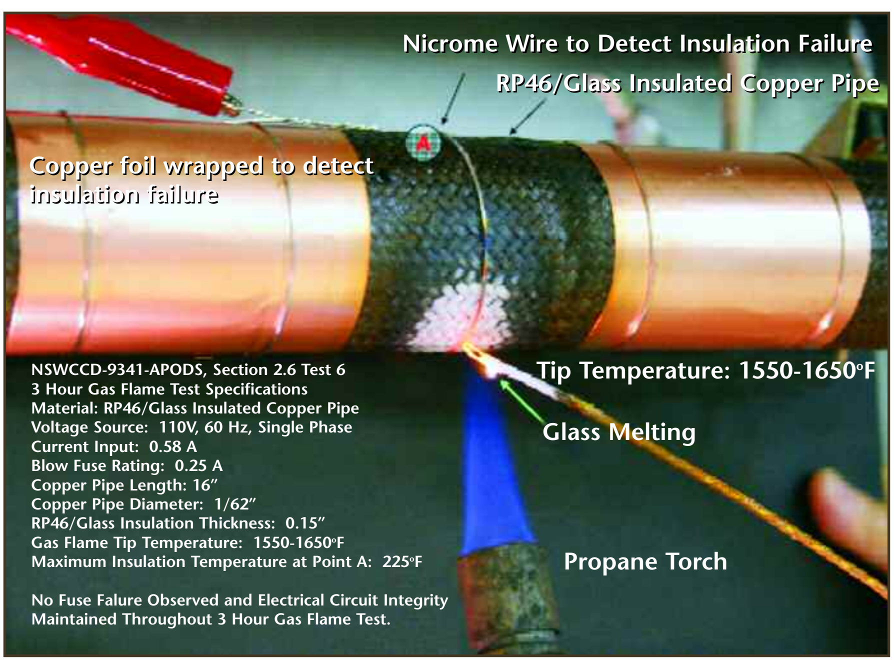
completely outfit the electrical distribution system in a modular unit and conduct electrical systems testing. If a component failure is discovered during testing, it is much easier to fix while the module is open ended. Connection of the IBP to the adjacent modules is analogous to connecting the piping systems, allowing the shipbuilder to realize additional efficiencies and cost savings.

Electrical power distribution system survivability is a unique Navy requirement. Rubber-jacketed cable offers little protection from ordnance damage. Building protective steel enclosures around susceptible cable runs can be done but at the cost of adding size, weight, and expense to shipboard construction. Stainless steel jacketed IBP subjected to ordnance effects by the Carderock Division was found to provide increased distribution system survivability.

With the apparent advantages of IBP compared to traditional cable for shipboard applications, Program Executive Office Carriers (PMS 378) sought an approach to determine if the commercially available IBP could be certified to distribute 13.8 kV electric power aboard the CVN 21 shipboard platform. Carderock Division proposed a test certification program, based on applicable tests taken from the Northrop Grumman Newport News (NGNN) cable specifications. Military standard shock and vibration tests and survivability testing to characterize the IBP's resistance to live ordnance were added to the certification requirements. The final certification plan was approved by NAVSEA's Marine Engineering group. With an approved test plan, Carderock Division imported test samples from two international vendors. Testing took place at the Carderock Division in Philadelphia and at various commercial and military test laboratories and facilities.

Test results were evaluated by NAVSEA for Navy shipboard certification. All of the test results were within acceptable ranges, except for the ability of the IBP to withstand a 3-hour gas flame circuit integrity test. This test, which is also a significant challenge for traditional cables, showed the commercial insulating resin used in the IBP was inadequate. Carderock Division, teaming with a NGNN advanced development representative, identified a new resin developed by NASA Langley which had an appropriate temperature rating. Leveraging this patented NASA development, Carderock Division, NGNN, and NASA Langley are working together to fabricate IBP test pieces to evaluate in FY08.

In addition to a form-fit-function replacement of existing medium voltage cable, IBP could provide a new shipboard electrical distribution system



Left: Gas flame test of RP46/glass insulated copper pipe.
Photo by NASA Langley.

paradigm. The ability of IBP to handle currents up to 8,000 amps at medium voltages combined with the recent development of in-line vacuum circuit breakers, or circuit interrupters, could enable new systems designs.

Carderock Division has been studying the potential shipboard use of multi-node IBPs with an in-line circuit interrupter at each node to allow rapid reconfiguration of electric power distribution, either manually or through algorithm-based decision-making software. The need for switchboards could be eliminated by placing distribution size in-line circuit interrupters anywhere on a ship. Rapid optimized reconfiguration of the power system in response to casualty conditions would enable a ship to continue its mission after an ordnance hit. Eliminating switchboards would increase survivability by doing away with the need to route power cable to centralized load distribution centers. Not only would the use of a multi-node IBP electrical distribution system reduce vulnerability and improve survivability, it could save significant weight and compartment space and reduce the cost of ship construction.

If proven a successful application, IBF will provide a capability that will be useful to the Navy by enabling a new Navy electrical distribution system that will reduce vulnerability, enhance survivability, and reduce the cost of ship fabrication.

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Implosion Research

Improving Safety of Submarine Pressure Hulls and Pressure Hull Systems

By R. Kent Tacey
Synopisized by William Palmer

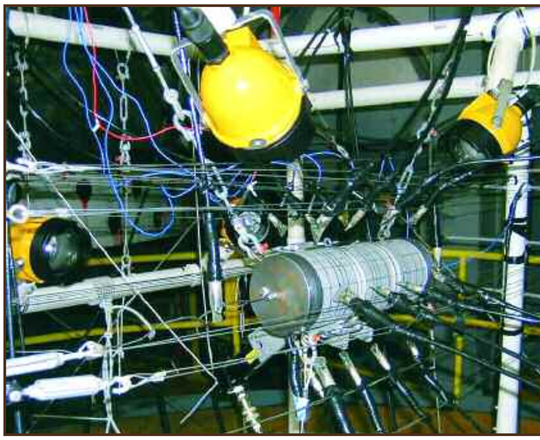
Naval Surface Warfare Center, Carderock Division (NSWCCD) directly supports the Submarine Forces Enterprise in the area of hull, mechanical, and electrical (HM&E) systems. One critical aspect of this is the safe performance of submarine pressure hulls and pressure hull systems. Future operations of the U.S. Navy's submarine fleet are projected to involve increased use of externally stored equipment. This may include items such as missiles, special operations forces equipment, sensor systems, and unmanned underwater vehicles. Because the equipment is externally stored, it is exposed to operational loads that include hydrostatic pressure and underwater explosion (UNDEX) loading. Much of this equipment incorporates air-backed structures that are liable to implode (collapse suddenly) due to operational loads.

An implosion event can involve a high-level energy release that could adversely affect submarine systems or the integrity of

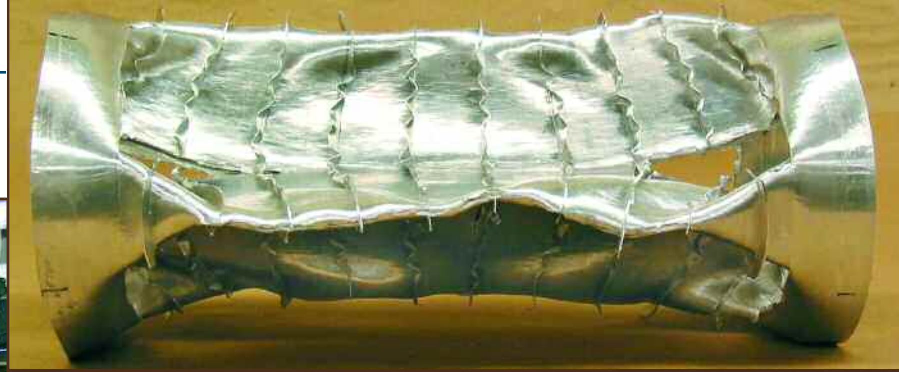
IMPLOSION RESEARCH (Continued on page 14)

Structures & Materials

IMPLOSION RESEARCH (Continued from page 13)



Above: The test configuration including the numerous pressure sensors.
Photo courtesy of R. Kent Tacey, NSWC Carderock Division.



Above: Implosion model after testing.
Photo courtesy of R. Kent Tacey, NSWC Carderock Division.

Left: A black-and-white frame captured from high speed video of an implosion event.
Videography by Neubar Kamalian, NSWC Carderock Division.

the vessel's pressure hull. Therefore, it is necessary to avoid a catastrophic implosion event. This can be done by designing the pressure-resistant structure of externally stowed equipment to withstand a very high pressure or by designing it to fail in a controlled manner that retards the implosion so that the associated energy release occurs more gradually. The current Navy design procedure for implosion is conservative and results in a relatively heavy pressure-resistant structure. This can result in extra cost and affect the feasibility or efficiency of the equipment. Therefore, the need arises for a new and more efficient implosion design procedure.

Advanced analytic procedure methods exist or are being developed that have the potential to be used in the analysis of an implosion event. However, they must be validated as to the accuracy of the analysis. Comparing analytical results to test data obtained from measurements taken during implosion events does this. Unfortunately, there is little available experimental data of the type required. Recently, the Office of Naval Research (ONR) funded research at NSWCCD and Naval Underwater Warfare Center, Newport Division (NUWCNPT) to conduct research into the basic mechanics of implosions. The ONR Basic Program builds on internally funded programs at both NUWCNPT and NSWCCD and is in its fourth and final year. Other participants include Naval Surface Warfare Center, Indian Head; Weidlinger Associates, Inc.; and the University of Maryland.

The goal of the Basic Program is to develop analytic capability to accurately predict implosion phenomena and to investigate the effect of various structural parameters on the implosion pressure pulse. NUWCNPT works to develop analytic procedures using the DYSMAS finite element code. DYSMAS is used for simulating the structural response of submerged and partially submerged structures to larger strain rate loadings such as blasts. NSWCCD designs, fabricates, and tests structural models in its high-pressure hydrostatic test facilities to provide test data to be used in analytic development.

The first series of tests involved the implosion of models fabricated with borosilicate glass and consisted of models with four different cylindrical geometries and one spherical geometry. These models were loaded to the designated test pressure and then implosion was initiated mechanically. The idea of using glass to fabricate the models was to have the structure fail nearly instantaneously upon implosion resulting in collapse of a void in the water. This would provide data to validate calculations that would not have to account for collapsing structure.

The second test series involved the implosion of 14 unstiffened, metallic cylinders with three different length-to-diameter (L/D) ratios. Three different materials were used and some of the models were coated with explosive resistant coating (ERC). The goal in this series was to provide data on the effects of ductility, geometry, thickness variation, and ERC on the measured implosion pulse of simple metallic structures. These models were loaded to the designated test pressure, and then implosion was initiated mechanically.

The third series of tests involved the implosion of nine stiffened, metallic cylinders with two different L/D ratios. The same material was used for all models; some of the models were coated with ERC. Different stiffening systems were used on six of the models, and the three remaining models were duplicates coated with ERC. The goal in this series was to provide data on the effects of different failure modes and ERC on the measured implosion pulse of metallic structures. These models were loaded to the designated test pressure, and then implosion was initiated mechanically.

A fourth series of six tests is planned that will involve the implosion of geometrically similar, unstiffened, metallic implodable volumes designed to fail in two different modes. The first two tests will measure the free field implosion characteristics of the volumes. The remaining tests will be conducted with a ring-stiffened cylinder called an adjacent structure model (ASM) present in the tank at the time of implosion. The distance (stand-off) between the ASM and the implodable volumes will be varied, and the response of the ASM model to the implosion of the smaller volumes will be measured. Implosions will be hydrostatically initiated, and additional instrumentation, including velocity meters and strain gages, will be used in this test series.

The basic program is a predecessor of a larger ONR Future Naval Capabilities (FNC) program to provide the test, design, and analysis capabilities necessary for the Navy to safely evolve toward submarine forces with more remote vehicles and external stores. Specifically, the FNC program will further develop analytic methods for implosion research, design, fabrication, and test full-scale structures for the deep ocean environment and develop an improved design tool for Navy structures.

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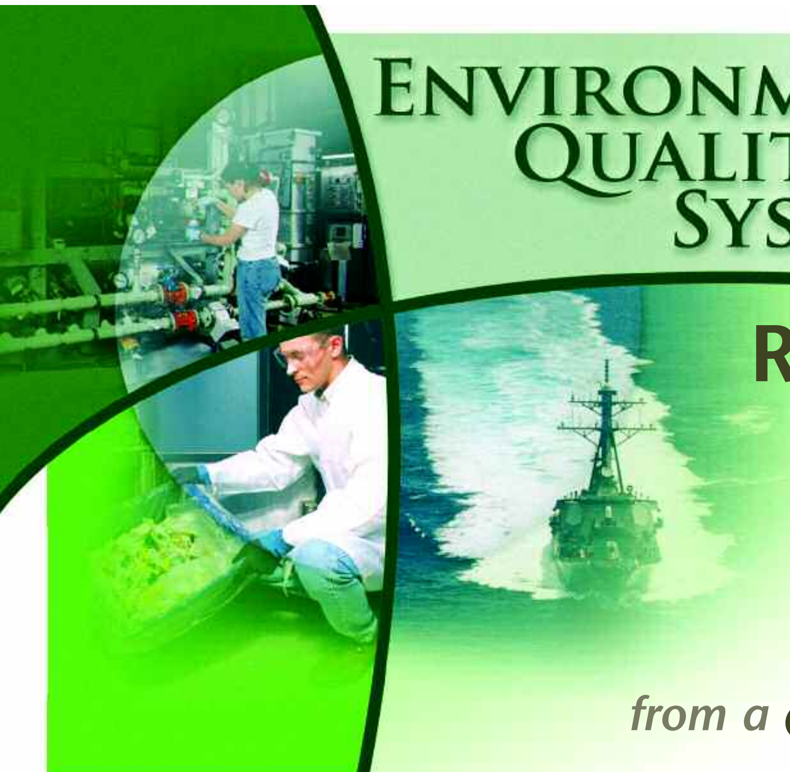


Environmental Quality Systems

Reducing Diesel Fuel Discharge

Understanding Characteristics of Fuel Droplets Discharged from a Compensated Fuel/Ballast Tank

By
Jerry W. Shan, Paisan Atsawapranee, Peter A.Chang, Wesley M.Wilson, and Stephan Verosto
Synopized by
William Palmer

The generation of droplets by the motion of two immiscible, or non-mixing, fluids occurs in situations as diverse as the liquid emulsions used for dispersed-phase reactions in chemical engineering operations or the oil-in-water emulsions of common salad dressings. An oil-in-water dispersion of interest for environmental reasons is the diesel fuel discharged in droplet form during the refueling of compensated fuel tanks on naval vessels.

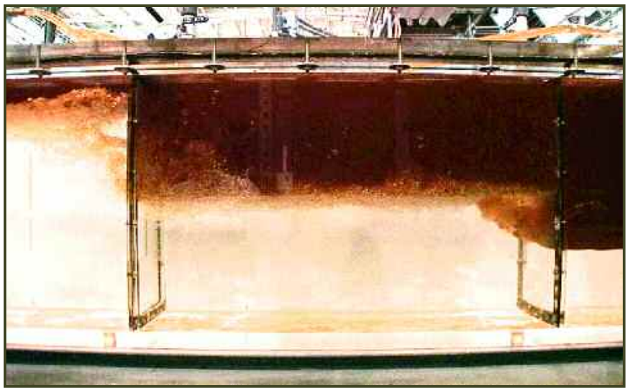
Compensated fuel/ballast systems are used by the U.S. Navy in the CG 47, DDG 51, and LHA 1 Classes, and more recently in the LHD 7 and 8 Classes, to maintain uniform trim and draft. In such ships, when fuel is consumed, the volume it occupies is replaced by seawater from the ships' firemain to compensate for the change in volume. During the refueling process, the discharged compensating water can potentially carry concentrations of fuel oil in excess of environmental regulations, even

REDUCING DIESEL FUEL (Continued on page 16)

REDUCING DIESEL FUEL (Continued from page 15)

bulk fuel in extreme cases. Both U.S. Navy instructions and international regulations direct that overboard discharges shall contain no more than 15 ppm of oily waste.

The overall effect of these regulations is to potentially limit the operations of compensated fuel/ballast ships by placing severe restrictions on their refueling.

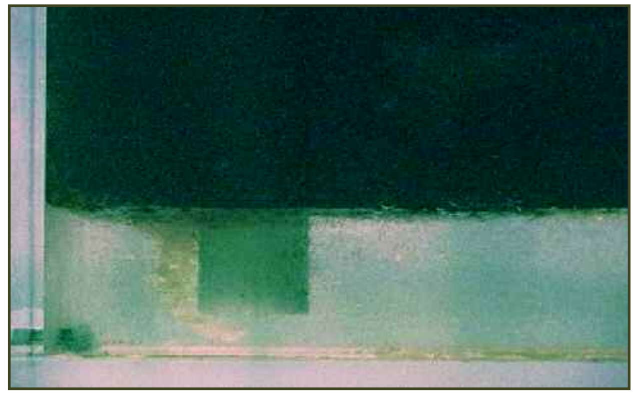


Above: Visualization of a buoyant flow event during a refueling test.
Image courtesy of Stephan Verosto, NSWC Carderock Division.

For this reason, the U.S. Navy has considerable interest in studying and modeling the flows which generate and transport immiscible droplets. One of the main goals was to develop solutions to reduce or eliminate fuel in the overboard discharge of compensating water. The solutions (depending on ship hull and tank designs) proffered may include modifying refueling procedures, tank structures, and/or level indicating devices.

A computational fluid dynamics (CFD) model, which simulates the fuel/water hydrodynamics and predicts the effluent fuel concentration, was developed by Naval Surface Warfare Center, Carderock Division (NSWCCD) as part of this process. The CFD model has proven to be accurate in predicting both water hideout (areas within the tank in which seawater is permanently trapped due to the tank's internal structure) and mass fuel discharge during tank refueling. To predict effluent fuel concentration during the refueling process, computational sub-models are needed that simulate immiscible droplet formation and entrainment and predict the number and sizes of droplets generated and carried with the compensating water to the tank exit.

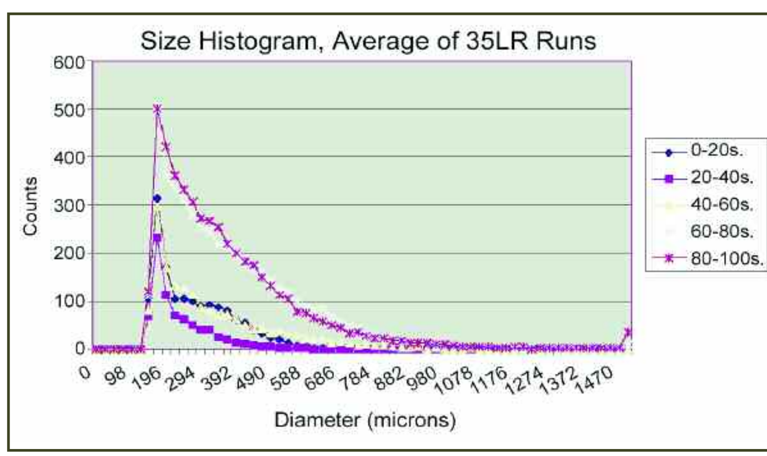
Data from physical model experiments performed in the small-scale experimental laboratory at NSWCCD are necessary for the sub-model formulation, calibration, and validation. Although it is evident from these experiments that several mechanisms play a role in generating the fuel droplets which contribute to the fuel concentration in the discharged water, buoyant flow events appear to dominate in importance. A buoyant flow event forms when fuel spills through a manhole connecting two adjacent bays, creating a positively buoyant jet which impacts upon a fuel/water interface underneath the tank top. This mechanism has shown to be a significant source of fuel droplet distribution in the generation zone. By obtaining quantitative measurements of the fuel droplet population at the tank outlet, the fuel concentration in the overboard discharge can be predicted. Simultaneous visualizations of the flow inside



Above: Visualization of draw-down near the effluent pipe during a refueling test.
Image courtesy of Stephan Verosto, NSWC Carderock Division.

the fuel tank also allow causal relations to be drawn between effluent fuel concentration and specific events within the tank.

From work accomplished during droplet formation and entrainment visualization experiments, researchers can conclude that effluent fuel concentrations are primarily attributable to events such as the buoyant flow, that the size distribution of the droplets discharged through the effluent pipe broadens as refueling progresses, and that even though droplets of the modal diameter (170 μm) are greatest in numbers, their smaller size make them relatively insignificant in terms of the contribution to the overall



Above: Droplet sizes in the effluent pipe during a refueling test.
Image courtesy of Stephan Verosto, NSWC Carderock Division.

effluent discharge. The peak of the contribution to the overall effluent discharge occurs around the droplet size of 590 μm.

The examination and experimental validation of computational sub-models designed to predict droplet formation and entrainment is one piece of the puzzle. Through this work the U.S. Navy moves closer to completing its goals of creating a CFD model capable of predicting effluent fuel concentrations in the discharge of compensated fuel ballast tanks and to providing design solutions to optimize the performance of the tank systems.

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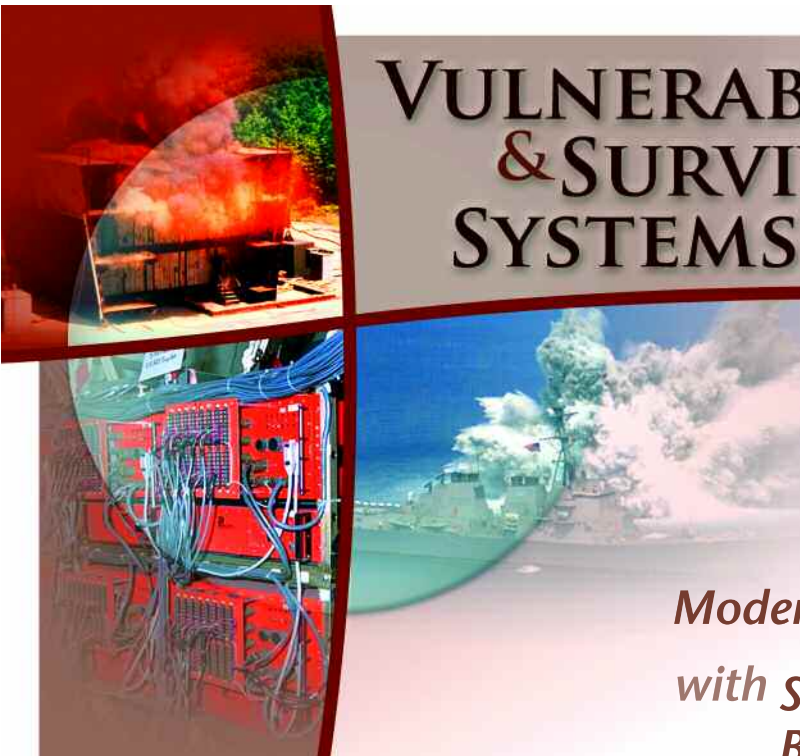

VULNERABILITY & SURVIVABILITY SYSTEMS

A BREATH OF FRESH AIR

Modernizing the Navy with State-of-the-Art Self-Contained Breathing Apparatus

By Dave Thompson and Leslie Spaulding

When it comes to damage control and firefighting, nothing ranks higher than safely protecting our fleet Sailors. Under a $150-million, multi-year program, the Navy is working toward modernizing its fleet with state-of-the-art damage control/firefighting and personal protection equipment. Rapidly converting the fleet from an antiquated oxygen breathing apparatus (OBA) used since 1945 to the self-contained breathing apparatus (SCBA) is part of this effort.

The SCBA and breathing air system was developed for U.S. Navy ships in a joint effort headed by the Naval Sea Systems Command, with support from in-service engineering agents from Naval Surface Warfare Center, Panama City, as well as Carderock Division, Type Commanders, and several original equipment manufacturers. Although SCBA has been used shoreside and with civilian firefighters for years, its use in the fleet is relatively new. The delay in converting was due to the high cost of refitting every ship in the fleet. However, as the old technology became more and more outdated and problems began to arise with the manufacturing of the OBA canisters, which also posed a safety hazard, the potential benefits to the Sailors outweighed the cost–and conversion began.

Problems with the OBA canisters and mix of chemical compounds inside the canisters posed a potential risk of an out-of-control exothermic reaction. This posed a burning risk to Sailors when used, as well as a danger

BREATH OF FRESH AIR (Continued on page 18)

Above: Navy Reserve Chief Warrant Officer Vu Duck, an instructor at Navy Center for Naval Engineering, instructs Sailors on the proper method for donning a self-contained breathing apparatus during a basic firefighting class. *U.S. Navy photo by Mass Communication Specialist 1st Class George Labidou.*

Right: Damage Controlman Fireman Dominic Green performs regular maintenance to the self-contained breathing apparatus aboard the *Nimitz*-class nuclear-powered aircraft carrier *USS Harry S. Truman* (CVN 75). *Truman* and embarked Carrier Air Wing (CVW) 3 are underway on a regularly scheduled deployment in support of maritime security operations. *U.S. Navy photo by Mass Communication Specialist Seaman Apprentice Matthew Bookwalter.*

BREATH OF FRESH AIR (Continued from page 17)

when stored or transported. The Navy tested every OBA canister in the fleet using x-ray and high powered imaging recognition software to determine if a potential problem was present. According to Carderock Division's SCBA Installation Execution Manager Dave Thompson, not only were the OBAs a safety hazard, but they presented an environmental concern as well. Spent canisters required disposal through HAZMAT procedures. Furthermore, the OBA replacement would also solve problems with high life cycle costs and increasing difficulty in obtaining spare parts.

The SCBAs currently being installed are state-of-the-art, adhering to a recently revised National Fire Protection Association (NFPA) standard. The apparatus is a cylinder-fed, open circuit respirator that supplies positive pressure breathing air to the user. The SCBA

Above: Hose team members practice firefighting during a general quarters (GQ) drill in the ship's laundry room aboard guided-missile destroyer *USS Stethem* (DDG 63). During GQ sailors train to defend the ship, control battle damage, and perform first aid and life-saving techniques. The damage control training team members use a smoke machine to make the drills more realistic. *Stethem* operates out of Fleet Activities Yokosuka, Japan.
U.S. Navy photo by Mass Communication Specialist Seaman Kyle D. Gahlau.

Right: Interior Communications Electrician 3rd Class Mark Alejandro adjusts the straps on the mask of his self-contained breathing apparatus while dressing out for a main-space fire drill aboard guided missile destroyer *USS John S. McCain* (DDG 56). *McCain*, part of Destroyer Squadron (DESRON) 15, is underway on a scheduled deployment.
U.S. Navy photo by Mass Communication Specialist Seaman Kyle D. Gahlau.

consists of a 4500-psi air cylinder with a 30- or 45-minute capacity, a face piece, e-z flow regulator, pressure reducer, quick connect block, and harness. The ship's high pressure (HP) air system is modified to provide SCBA cylinder recharging capabilities. Portable emergency breathing air compressors are also installed as a secondary means of charging SCBA cylinders or are provided to ships that do not have HP air systems.

BREATH OF FRESH AIR (Continued on page 20)

BREATH OF FRESH AIR (Continued from page 19)

In coordination with Panama City, Carderock Division's Damage Control, Recoverability and Chemical Biological Defense Branch has successfully installed SCBAs on 134 in-service surface ships, including aircraft carriers, surface combatants, amphibious, and mine warfare ship classes. The Division has moved into the final phase which involves converting the PC 1 Class, the LCU Class, and USN drydocks to SCBA configurations. This effort is scheduled for completion this fiscal year. Submarine SCBA installations are also ongoing under the direction of Carderock Division's John Biedka of the Technology Deployment Branch.

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Signatures, Silencing Systems, & Susceptibility

Electromagnetic Research Measurement Array

Newly-Installed Underwater Electromagnetic Array Helps Carderock Division Meet Navy Missions

By James E. Miller
Synopsized by William Palmer

The Naval Sea Systems Command (NAVSEA) and Naval Surface Warfare Center, Carderock Division (NSWCCD) maintain a special purpose measurement system–the Electromagnetic (EM) Research Measurement Array (ERMA). This array is used to advance underwater electromagnetic silencing research and development and test and evaluation. ERMA was installed in 2006, approximately one nautical mile off shore from Ft. Lauderdale, Florida, in 70 feet of water. ERMA consists of an underwater array of magnetic and electric sensors and associated equipment to measure the ship EM signatures. The measurement capability provided by ERMA is essential

Above: An array sensor and its concrete base, with inset showing it in place underwater.

Top Left: Location of the Shallow Water Electromagnetic Range of the South Florida Test Facility.

Left: The South Florida Test Facility buildings.

All images courtesy of James E. Miller, NSWC Carderock Division.

to certify that the *Virginia* Class submarine meets its stealth requirements.

NSWCCD has had EM measurement capability at the South Florida Test Facility (SFTF) since 1979, but the original system, the Shallow Water Electromagnetic Range (SWER), had deteriorated. During a calibrated source test in 2005, it was determined that SWER performance had degraded to a point where the *Virginia* test and evaluation master plan (TEMP) objectives could not be met. The failure of hardware was both in-water and shore-side. It was determined that it would be necessary to design, develop, and install a new facility to ensure that the Virginia EM TEMP trials will be successfully executed and that the signature characterization and evaluation set up in the operational requirements document can be achieved.

Due to the SSN 774 EM trial schedule, the new array had to be operational by December 31, 2006. The resources required to perform this task were allocated in November 2005, which meant that the new array had to be designed, developed, installed, and tested in 13 months. The measurement facility was upgraded during the summer and fall of 2006 and renamed ERMA.

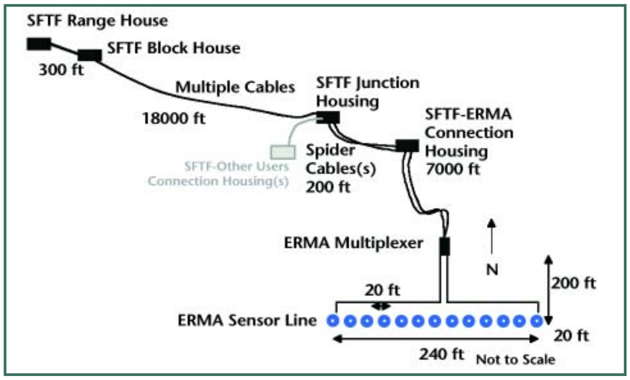
The work performed by NSWCCD Code 70 to develop ERMA involved the design, specification, installation, and calibration of a new 13-unit magnetic and electric sensor array. The new array uses state-of-the-art technologies and incorporates a new co-located sensor package to minimize maintenance and improve system robustness and reliability. Thirteen high-quality triaxial magnetometers and 13 triaxial underwater electric potential (UEP) sensors were installed at a nominal depth of about 65 feet below the mean lower low water (MLLW).

Several technological advances were incorporated into the new array, which allow the measurement of electromagnetic signature phenomena from DC through 3 kHz. A new data acquisition system produces digitized maps of array-crossing magnetic and electric signatures. Dual real-time kinematic (RTK) global positioning satellite (GPS) tracking is used to track surfaced vessels. The major enhancements incorporated into the array greatly improve the accuracy in measuring DC and AC, magnetic and electric, signatures of the Navy's fleet and further reduce on-site ship time.

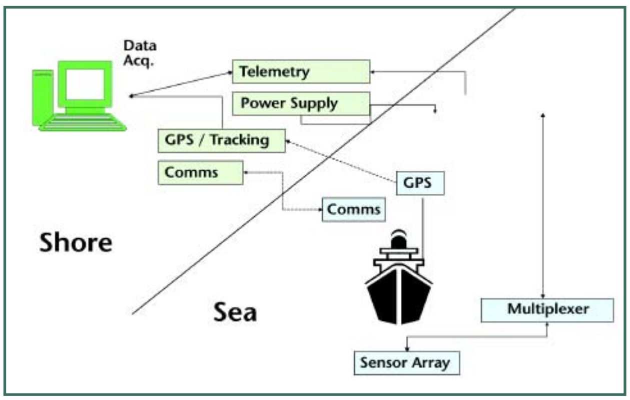
The ERMA system was designed to improve component robustness and performance when compared to the previous SWER hardware. The system components can be replicated in large quantities, for use at any number of sites and underwater topography. It was demonstrated during production of the 13-unit ERMA array that component hardware could be produced quickly, using readily available commercial materials and at a reduced cost (as compared to other sensor manufacturers) while still meeting reliability and critical corrosion standards for long-term submersion in a sea water environment

ELECTROMAGNETIC RESEARCH (Continued on page 22)

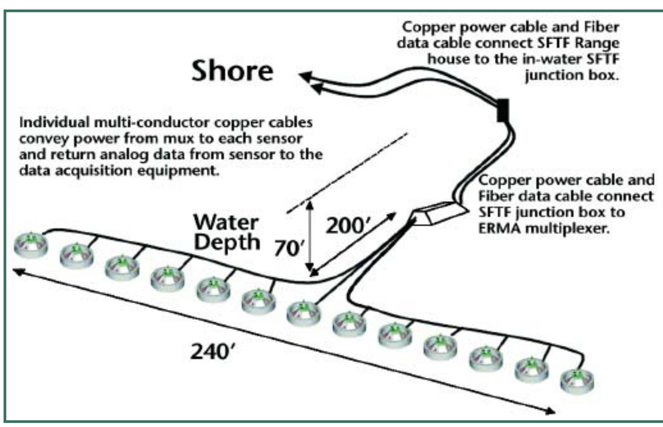
ELECTROMAGNETIC RESEARCH (Continued from page 21)



Above: System overview showing cabling from range house to sensor array.



Above: ERMA system diagram.

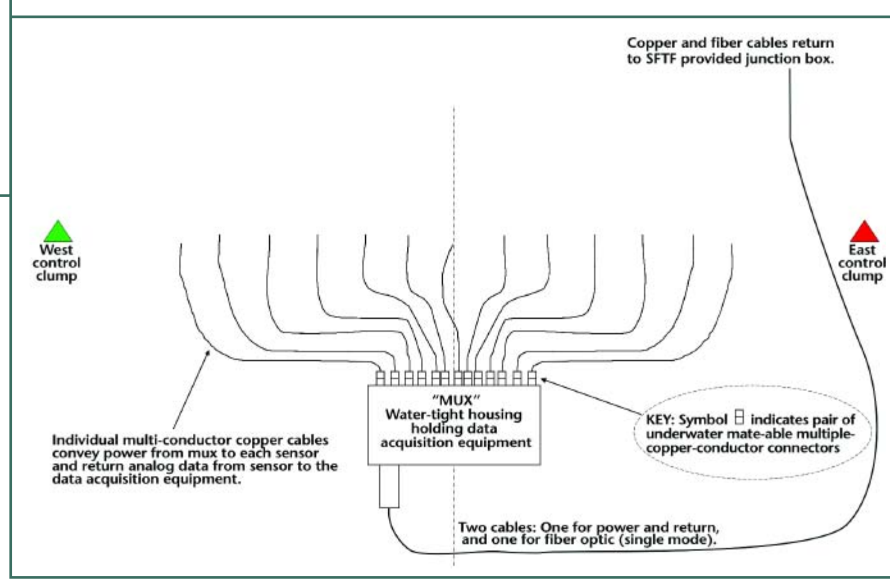


Above: Detail of sensor layout and cabling interconnections.

Above: Array sensors staged on a transport vessel for implant.
Photo courtesy of James E. Miller, NSWC Carderock Division.

After installation, ERMA's performance was verified using calibrated magnetic and electric sources. The results of the electromagnetic calibration study indicate that the performance of ERMA exceeds the design objectives. In fact, Dr. John Holmes, a Carderock Division Senior Scientist, and recent co-selectee for NAVSEA Scientist of the Year, reported, "The ERMA array produced the highest quality underwater electromagnetic signature data of any range, anywhere in the world."

The new ERMA array represents a major advancement in the Navy's magnetic silencing capabilities. The new array will provide state-of-the-art calibration and certification measurements for *Virginia* Class submarines and can be used for a variety of surfaced vessels. Analytical tools for EM silencing have improved



Above: One-line diagram detailing the underwater portion of the array.
All graphics courtesy of James E. Miller, NSWC Carderock Division.

radically in the last several years. Advanced degaussing concepts have been investigated with the intent of reducing the vulnerability of the Navy's combatants in response to recent improvements in mine warfare and ship detection. All of these magnetic silencing enhancements depend on more accurate and detailed signature data, which is now provided.

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TECHNOLOGY & INNOVATION

DEVELOPING MAGNETOSTRICTIVE MATERIAL

Galfenol–A Disruptive Technology that Opens Future Opportunities

By Dr. James B. Restorff, Marilyn Wun-Fogle, and Dr. Arthur E. Clark

In late 1999, the Magnetic Materials Group at Naval Surface Warfare Center, Carderock Division (NSWCCD), invented an exciting new smart material: Galfenol, an iron-gallium alloy system. Galfenol is a magnetostrictive material with a combination of properties unmatched by any existing smart material. Magnetostriction is the name given to the process whereby some materials alter their physical dimensions when a magnetic field is applied to them. It is important because it offers an avenue to convert electrical energy into mechanical energy, similar to the more familiar electric motor. Magnetostriction is not new: It was discovered more than 150 years ago in 1847 when James Prescott Joule measured the change in length of an iron rod when it was placed in a magnetic field. In many applications magnetostriction is considered to be highly undesirable because it leads to audible noise and energy losses. One person's problem, however, is another person's opportunity, and materials with large magnetostrictions have proven to be technologically valuable. In World War II, the United States and its allies used nickel in sonar transducers. Magnetostrictive materials were so crucial to the war effort, that the Japanese, for whom nickel was unavailable, developed a new iron-aluminum magnetostrictive alloy to perform the same function.

Galfenol is the second room temperature magnetostrictive material with large magnetostriction discovered by the group. Funded by the In-House Laboratory Independent Research (ILIR) and Office of Naval Research (ONR) at the Naval Ordnance Laboratory (now the Naval Surface Warfare Center), the Magnetic Materials Group began a search for materials with room temperature magnetostrictions larger than that provided by nickel and iron-aluminum. This culminated in 1979 with the discovery of the technologically useful giant magnetostrictive alloy Terfenol-D ($Tb_{0.3}Dy_{0.7}Fe_{1.93}$) which has a useful strain of ~1800 ppm. The name is derived by taking Ter from terbium, fe from the chemical symbol for iron, nol from the Naval Ordnance Lab, and D from dysprosium and is now commercially available. Galfenol is named similarly to Terfenol-D with Gal from gallium, fe from the chemical symbol for iron, and nol from the Naval Ordnance Lab.

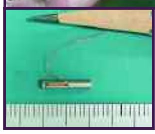
In 1998, the NSWCCD Magnetic Materials Group began a search for another magnetostrictive

MAGNETOSTRICTIVE MATERIAL (Continued on page 24)

MAGNETOSTRICTIVE MATERIALS (Continued from page 23)

Left: Carderock Division's Scott Hoover machines a rod of a directionally solidified Galfenol alloy with Arthur Clark of Clark Associates looking on.
Photo by James Restorff, NSWC Carderock Division.

Left: A directionally solidified Galfenol alloy shown with a machined surface.
Photo by James Restorff, NSWC Carderock Division.



Left: Magnetostrictive microactuator utilizing stress annealed Galfenol as the active element. This microactuator is small and simple. It requires a low driving power but has a high power output and high mechanical tolerance. Applications envisioned for this microactuator are as a micro speaker, micro injector, and new actuation components. This work is performed under a Naval International Cooperative Opportunities Program between Carderock Division and Mechano Transformer Corporation and University of Tokyo in Japan.
Photo by Toshiyuki Ueno, University of Tokyo.

material that was less expensive, could support substantial amounts of both compressive and tensile force and had a high strain. The search was prompted by the brittleness of Terfenol-D and its ceramic counterparts. These materials cannot be exposed to tensile stresses during either operation or handling. This search also ended successfully with the discovery of the Galfenol.

Magnetostrictive materials can produce very high forces, but the range of motion is small. A 2.5 inch diameter rod of Terfenol-D 10 inches long, for example, can lift an 80,000 pound object, e.g., a fully loaded tractor trailer truck, 0.018 inches with the application of a modest magnetic field. These materials utilize low voltages and generally are rugged, impervious to adverse environmental conditions, and have a record of high reliability.

The Galfenol alloys fill an empty place in the spectrum of smart materials. They are mechanically tough and have saturation magnetostrictions as high as 400 ppm in single crystal form and 300 ppm in the more easily produced highly textured polycrystalline form. Furthermore, these alloys can sustain approximately 400-500 MPa (58-75 kpsi) of tensile stress. They can be machined and welded with conventional metalworking technology. The full magnetostriction can be accomplished with an easily obtainable magnetic field. A target application for such an alloy is active vibration control. One can imagine a vibrating piece of machinery mounted on a frame made of such an alloy. A single layer coil wound around pieces of the frame would allow active control of the vibration.

This effort has been funded both by Carderock Division's ILIR program and by ONR's Ocean Sensing and Systems Applications Division. Jan Lindberg, the ONR sponsor, comments, "The Magnetic Materials Group at Carderock has once again come up with an amazing new material! Galfenol is a new active transduction material that both answers many current needs and challenges transducer designers to discover new mechanisms that, before the advent of the material, could not even be imagined. It is truly a disruptive technology because it is simple yet complex."

The Galfenol material is scientifically as well as technologically interesting. Unlike previous active materials, the physical mechanism that generates the magnetostriction is not well understood. The elucidation of this mechanism is part of an ongoing ILIR program at Carderock Division.

An active effort is being made to shorten the usual 20-year time frame between the discovery and commercial/military use of a new material. Jon Snodgrass, Executive Vice President and Chief Scientist at ETREMA Products, Inc., which is pursuing commercialization remarks that, "Galfenol faces the challenge of the long development cycle inherent to any emerging material technology. However it also offers many opportunities in the form of applications that were simply impossible due to the limits of legacy active materials. The task of the Galfenol research community is to focus on applications that utilize the material's unique characteristics as those solutions have the greatest potential to help drive the maturation of the technology."

Since the discovery of Galfenol in 1999 it has advanced from being a curiosity in an NSWCCD laboratory to a material being investigated worldwide by a variety of university and government laboratories. In the United States, efforts to commercialize the material are well underway and showing substantial progress. We believe this material has a bright future and brings to the designer a material with heretofore unavailable performance.

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